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CRACKS TORQUE OF T SECTION R.C BEAM WITH WEB PERFORATION USING REACTIVE POWDER CONCRETE

ALI SABAH AHMED ALAMLI[1], HAYDER ABDULAMEER MEHDI[2] & REEM HATEM AHMED[3]

[1,2]Assistant Professor, Department of Civil Engineering, AlMustansiriya Engineering College, AlMustansiriya University, Baghdad, Iraq

[3]M.Sc. Student, Department of Civil Engineering, AlMustansiriya Engineering College, AlMustansiriya University, Baghdad, Iraq

ABSTRACT

A series of ten T section reinforced concrete beams by use Reactive Powder Concrete (RPC) with square and circular web perforation. The geometry and main reinforcement of all specimens are same and was investigated under the effect of pure torsion. The main parameters taking into account in present paper are circular opening size, location of openings, and number of openings. The torque caused the first crack was recorded and the angle of twist generated from this torque was calculated for different parameters mentioned above. The results indicated that the crack torques for first crack decrease in presence of opening and the crack torques decrease when the opening increased.

KEYWORDS: Torque, Cracks, RPC, Web Perforation, T Section

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Original Article

INTRODUCTION

A reinforced concrete beam has cracked in torsion, its torsional resistance is provided primarily by closed stirrups and longitudinal bars located near the surface of the member [1]. A beam with opening in the web has many advantages in modern structural design. Introduced opening like circular, square, and rectangular or any shape has advantages to use it to pass services. The shape, size and location of web opening relay on the purpose of opening but the presence of opening reduce the stiffness of the beam and the opening make the deflections higher when coMPared with solid web.

Reactive Powder Concrete (RPC), improved the important properties of concrete that is compressive strength, tensile strength, flexural strength and Young's modulus of elasticity. Torsional resistance of RC beams by using closed stirrups and main reinforcement at the sides. In 2015, Hisham Mohamed et al, [2], tested and investigated the behavior of ten reinforced concrete specimens of T sections with and without hole along the span under pure torsion and using reactive powder. Authors focused on the effects of holes and steel fibers on the cracks and full capacity of T sections under pure torsion. By results from experimental tests, increased in capacity for solid section is more than if coMPared with hollow section in case of presence of steel fibers but the core has no effect on the ultimate torsion capacity. In 2015, Waleed Awad et al, [3], studied the ultimate strength of hollow RC beams under pure torsion. The investigation consists of solid and hollow section with eighteen percent for circular opening and eighteen, twenty seven percent for rectangular opening from the total depth of beams. Torque – twist and opening effects on it and on the full behavior of RCC beams discussed by authors. Researchers concluded that

the full capacity torque of hollow section in case of circular is greater than in case of rectangular hollow when compared with solid section. In 2015, Hisham Mohamed et al, [4], suggested an empirical formula by using regression method to estimate torsional capacity in case of presence steel fiber. The two proposed formula deals with codes formula and derived from tests result. In 2015, Haneen Maad [5], investigated the behavior High Strength Self CoMPacted "HSSC" of hollow section RCC beams under pure torsion. The total six beams was tested has same geometry and length, so the main variables was the stirrups spacing. The experimental tests result indicated that the torsion beams resistance increased by decreasing of stirrups spacing, also, the improvements of ultimate torsional capacity coMPared with reference beam up to two hindered fifty percent and for torsional cracks up to two hindered percent. In 2013, Wissam Kadhum [6[, investigate RPC beams subjected to pure torsion by tested the strength capacity and torsional cracks of beams experimentally and theoretically. The experimental work consists of twenty two T section of RPC with various fiber steel ratios and silica fume subjected to pure torsion. Theoretical approach using tests results and proposed empirical equations represent cracking torque as a function of properties of RPC and another proposed equation to estimate maximum torsion relay on the properties of RPC. Tests result indicated that in presence and using of RPC up to (2%) increased the cracking torsion and then after increased in full torsional capacity. In 2013, Raid I. Khalel [7], investigated RC beams under pure torsion in case of high strength concrete type. Forty three specimens was adopted by author from literature review and applied regressions method to suggest an empirical equations, cracked due to pure torsion and resistance or torsional capacity as a function of concrete compressive strength, geometry longitudinal and transverse reinforcement. In 2012, Raed Hamed [8], investigated the behavior of RC beams in presence of steel fibers and self-coMPact under pure torsional loading. Angle of twist and strain resulted from applied torsion was coMPared for all concrete types. In 2010, Wameedh Ghassan [9], investigated the torsional capacity of tested reinforced concrete "RC" beams as a function of various variables like fibers amount, with and without openings, and reinforcement ratio in each directions. The researcher founded that adding one percent of steel fiber increased the torque and reducing cracking.

Experimental Program

The dimensions of T-beam in present study are (bw=100mm, h=280mm, bf=320mm. tf=80mm), with length of (1300 mm). The reinforcement for beams with stirrups as distributed with bottom reinforcement 2Φ10, top reinforcement 2Φ 6, shear reinforcement Φ6 @ 200 mm. the total tested beams was ten beams have same geometry and steel reinforcement.

Specimen's Details

The main variables adopted in the experimental work as follow; reactive powder concrete (RPC) and modify reactive powder concrete (MRPC), Eight T-section beams made of (RPC) and two T-section beams made of (RPC and MRPC) one of beam made of (RPC) in web and (MRPC) in flange, then another beam made of (MRPC) in web and (RPC) in flange. Monolithic and non-monolithic beam: Nine T-section beams cast monolithically and One T-section beam made of (RPC) cast non-monolithically. Web Opening: the opening in this study contains many variables in (shape, dimension, location, number).

Opening Layout

The openings layout and configurations in the web of the T-section beams, one solid beams without web opening were made of (RPC), and nine other beams with different locations and sizes that perforated in web openings as follow:

shape of opening (circle, square), dimension, circle Φ 100mm- Φ 150 mm, square 100*100mm, location at (1/3 of beam, centre of beam), number, nine of beams contains one opening in the web and the other contain two opening in the web. The details of beams and openings listed in Table 1.

Table 1: Details of Beams and Web Openings

Specimen Mark	Material	Details of Opening
R SOLID	Solid beam made of (RPC) cast monolithically	NO OPENING
RCC	Made of (RPC) cast monolithically	Circle Φ 100mm @ center of beam
RSC	made of (RPC) cast monolithically	Square (100*100mm) @ center of beam
RCS	made of (RPC) cast monolithically	Circle Φ 100mm @ 1/3 of beam
RSS	made of (RPC) cast monolithically	Square (100*100mm) @ center of beam
R2C	made of (RPC) cast monolithically	Circle Φ 100mm @ center of beam and Φ 100mm @ 1/3 of beam
RC big	made of (RPC) cast monolithically	Circle Φ 150mm @ center of beam
MFCC-RWCC	made of (MRPC)in flange and (RPC) in web cast monolithically	Circle Φ 100mm @ center of beam
RFCC-MWCC	made of (RPC)in flange and (MRPC) in web cast monolithically	Circle Φ 100mm @ center of beam
R-CCnon monolathic	made of (RPC) cast non monolithically	Circle Φ 100mm @ center of beam

MATERIAL

Two types of concrete mixes are used Reactive Powder Concrete (RPC) and Modified Reactive Powder Concrete (MRPC). The (RPC) and (MRPC) mixes production requires high quality materials. Usually chemical admixtures are employed to obtain a low water–cement (w/c) ratio with acceptable workability.

Cement

Ordinary Portland cement type (I) Mass (Sulaymaniyah) in Iraq was used for both (RPC) and (MRPC). Tables 2 list the results of physical properties of the cement. Results indicate that the available cement conforms to the Iraqi Specification (IQS) No.5/1984[10].

Table 2: Physical Properties of Cement

Physical Properties	Test Result	Limit of Iraqi Specification No.5/1984
Specific surface area (Blaine Method), m^2/kg	383	230 (min)
Setting time (vicat's method) Initial setting, hrs: min Final setting, hrs: min	1:55 4:25	00:45 (min) 10:00 (max)
Compressive strength, MPa 3 days 7 days	25.85 28.00	15.00 (min) 23.00 (min)
Autoclave expansion %	0.01	0.8 (max)

Fine Aggregate

Very fine sand with maximum size 600µm was used for (RPC) and (MRPC) Mixes. The grading of used fine sand conform to the Iraqi specification(IQS) No.45/1984[11]

Coarse Aggregate

Crushed gravel from AL-Nibaey region was used for modified reactive powder concrete (MRPC) mixes with a maximum size of 5mm. This crushed gravel was washed, then stored in air for surface drying, and then stored in a saturated surface dry condition before using.

Silica Fume

The silica fume (SiO_2) reacts with this calcium hydroxide to form additional binder material (calcium silicate hydrate (C-S-H)) which is very similar to the calcium silicate hydrate formed from the Portland cement [12]. In present paper, Silica fume has (20%), cement mass for (RPC) and (10%), cement mass for (MRPC). The chemical composition of this silica fume conform s to the ASTM 1240-04 [12]. High range water reducing agent HRWRA) based on poly carboxylic ether is used. One of the new generation of polymer based super plasticizer Glenium 51 is used, the normal dosage for is (0.5-0.8) L/100kg of cement mass. it is free from chlorides and complies with ASTMC494 [13] types A and F.

Steel Fibers

Hooked ends short steel fibers were used in this work with volume fractions of (V_{sf} =1%). The properties of the used steel fibers are shown in Table 3.

Table 3: Properties of Steel Fiber

Property	Specifications
Relative density	7860 kg /m^3
Yield strength	1130 MPa
Modulus of elasticity	200x10^3 MPa
Strain at portion limit	5650x10^{-6}
Poisson's ratio	0.28
Average length	32 mm
Nominal diameter	0.4 mm
Aspect ratio(L_f/D_f)	80

Steel Reinforcement

Longitudinal reinforcement with diameters (10mm) used for main reinforcement and (6mm), which are used for stirrups. The bars have been tested in the material laboratory of the Civil Engineering Department at Al-Mustansiriyah University, test results of steel bars conform to (ASTM A615/615M-13) [14], the results listed in Table 4.

Table 4: Properties of Steel Bars

Nominal Diameter (mm)	Measured Diameter (mm)	Modulus of Elasticity(E_s) (GPa)	Yield Stress(f_y) (MPa)	Ultimate Stress(f_u) (MPa)
10	9.53	200	484	719
6	6.17	200	385	550

Mixing (RPC)

Reactive powder concrete consisting of cement, fine sand, silica fume, steel fibers, super-plasticizers and water were used to cast the RPC beams, as well as the control specimens (cubes,cylinders and prisms) of RPC. The composition of RPC with a water to cement ratio of 0.2, percentage of silica fume was (20%) by weight of cement, and very fine sand was used with maximum particles size of (600µm), Table 5 list concrete mix for (RPC).

Table 5: Properties of Concrete Mix (RPC)

Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Silica Fume* %	Silica Fume kg/m^3	w/c	Super-Plasticizer (L/m^3)	Steel Fiber Content** %	Steel Fiber Content kg/m^3
1000	1000	____	20	200	0.2	5	1	78

The composition of MRPC with a water to cement ratio of 0.2, percentage of silica fume was (10%) by weight of cement, and very fine sand was used with maximum particles size of (600µm). The used super-plasticizer gives enough mixing time and permits to produce uniform mixing of concrete without any segregation, Table 6 list the concrete mix (RPC).

Table 6: Properties of Concrete Mix (MRPC)

Cement kg/m^3	Sand kg/m^3	Gravel kg/m^3	Silca Fume* %	Silica Fume kg/m^3	w/c	Super-Plasticizer (L/m^3)	Steel Fiber Content** %	Steel Fiber Content kg/m^3
900	600	540	10	90	0.2	5	1	78

Classifications of tested specimens

Table 7 listed the tested beams classifications and containing all geometry, opening sizes, opening locations, compressive strength, cracked torque with angle of twist, and percentages of cracked torque from ultimate torque. Figure 1, show the tested beams layout with all dimensions.

Table 7: Tested Beams Classifications

Specimen Mark	Geometry (mm)	Opening Size (mm)	Opening Location	Compressive Strength (MPa)	Crack Torque (kN.m)	Angle of Twist (Rad.)	% (T_{cr}/T_u)
B1 RSOLID				130	132.5	-2.1737	75.28
B2 RCC	circle	Diameter 100mm	@center of beam	130	100	-1.1459	65.78
B3 RSC	square	100*100 mm	@center of beam	130	92.5	-0.8693	67.27
B4 RCS	circle	Diameter 100mm	@1/3 of beam span	130	85	-0.5136	66.40
B5 RSS	square	100*100 mm	@1/3 of beam span	130	79.5	-0.3161	66.25
B6 R2C	Circle	Diameter 100mm	@1/3 of beam span @center of beam	130	75	-1.2645	63.55
B7 RC big	circle	Diameter 150mm	@center of beam	130	55	-0.1659	55.00
B8 MFCC-RWCC	circle	Diameter 100mm	@center of beam	130 FOR R.P.C 92.5 for M.R.P.C	65	-0.6194	60.46
B9 RFCC-MWCC	circle	Diameter 100mm	@center of beam	130 FOR R.P.C 92.5 for M.R.P.C	60	-0.0395	58.53
B10 R-CC NON MONOLATHIC	circle	Diameter 100mm	@center of beam	130	72	-0.0580	62.60

Observations and Results

It was observed that there was warping cracks at the cracked torque stage because of it was subjected to very high torque caused cracks warped around the section and distributed along the beams. Figure 1 show the cracks pattern for all tested specimens, specimen number 1 represent the reference tested beam, the cracks occurred when the first increment of the load was applied, and both increased as the test progressed. The beam cracks start diagonally at 45^{o} from support. Measurements of twisted angle in all tests are plotted against the crack torque shown in Figure and also Figure 2 show the behavior of crack torque vs. angle of twist. Figure 3 show the variation of twisted angle with applied distance torque. The general behavior of all tested beams that the beams are loaded predominately in torsion and there are no combined stresses. At low applied torque, the angle of twist to small because of the displacement developed very small and there is no cracking was appearing. When the loading increasing, the first cracks was starting from support diagonally at 45^{o}. When the torque increased, the cracks become more and visible as warping in shape around the geometry along the span of beams. The results listed in Table (7) indicated that the presence of web perforation make the torque cracks less that is mean the presence of opening reduce the strength of beam. In beam number 7, there is a big hole and the result indicated that the first crack torque become small because of developed plastic hinge there.

Figure 1: Cracks Propagations for All Tested Beams

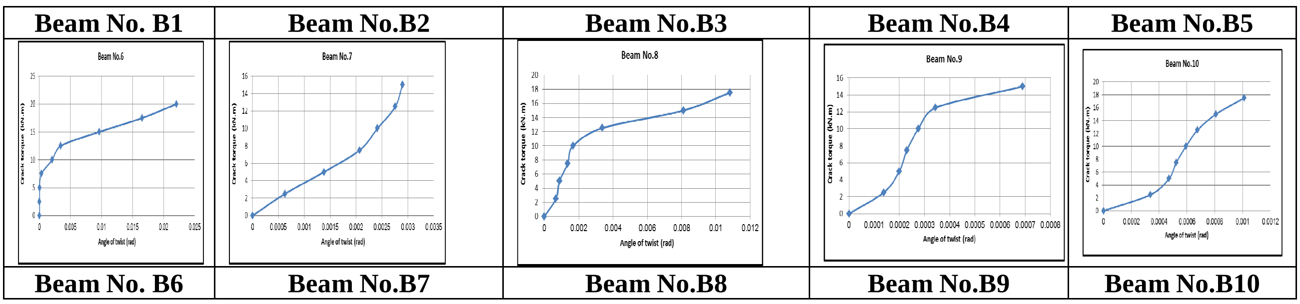


Figure 2: Cracks Torque – Angle of Twist Behavior for all Tested Beams

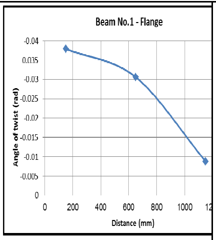
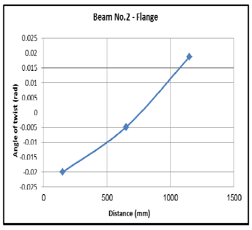
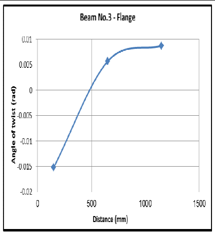
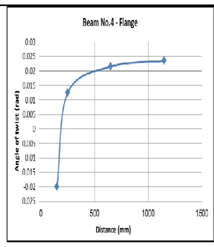
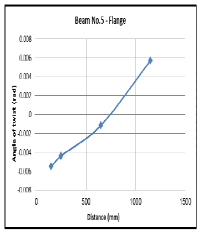
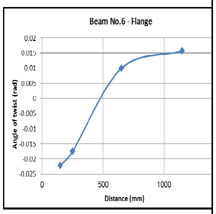
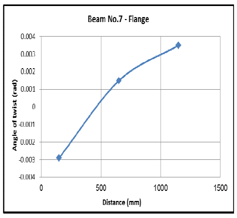
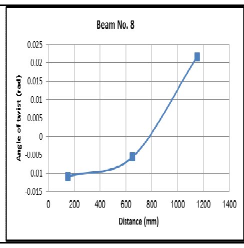
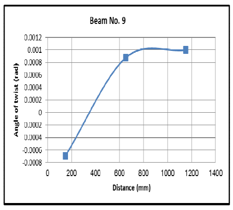
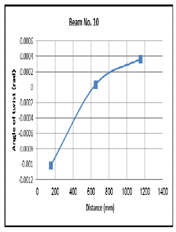
				
Beam No. B1	**Beam No.B2**	**Beam No.B3**	**Beam No.B4**	**Beam No.B5**
				
Beam No. B6	**Beam No.B7**	**Beam No.B8**	**Beam No.B9**	**Beam No.B10**

Figure 3: Angle of Twist - Distance Behavior for all Tested Beams

CONCLUSIONS

According to the results from experimental tests, the following conclusions were drawn:

- The crack torques need to cause first crack decrease in presence of opening.
- The crack torques decrease when the opening increased.
- Cracks density increased as the opening increased and become non-uniform.
- Cracks intensity becomes more at the location of eccentric opening.

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